BLM-AK-PT-88-005-1730-060

A Statistical Analysis and Summary of Radar-Interpreted Arctic Lake Depths:

an addendum to 12 map products

Jack C. Mellor

Twelve U.S. Geological Survey quadrangles (scale 1:250,000) on which radar-interpreted depths have been mapped

Barrow	Meade River
Harrison Bay	Misheguk Mountain
Howard Pass	Teshekpuk
Ikpikpuk River	Umiat
Killik River	Utukok River
Lookout Ridge	Wainwright

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All resolvable (>10 ha) lakes on 12 U. S. Geological Survey 1:250,000 scale quadrangles covering the National Petroleum Reserve in Alaska have been mapped to depict three depth ranges. The ranges were mapped by delineating the ~1.6m and ~4m radar-interpreted isobaths.

After a well-trained individual interpreted depths on all 12 quadrangles, fathometer transects were acquired on 157 field verification lakes for statistical comparison with radar-interpreted lake depths. Lakes depicting the ~1.6m radar-interpreted isobath were verified in 99 percent of the 109 test lakes sounded by fathometer. Mean horizontal displacement of the confirmed ~1.6m radar isobaths from the fathometer-determined 1.6m depth was 62m (predominantly shoreward). Lakes with interpreted depths >~4m were verified in only 63 percent of the 27 test lakes sounded by fathometer. Mean horizontal displacemnt of the confirmed ~4m radar-interpreted isobaths from the fathometer-determined 4m depth was 147m.

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Abstract

All resolvable (greater than 10 ha) lakes on 12 U.S. Geological Survey 1:250,000 scale quadrangles covering the National Petroleum Reserve in Alaska have been mapped to depict three depth ranges. Radar images acquired over NPR-A in April of 1980 were used as a test to interpret areas from shoreline to 1.6m, 1.6m to 4m, and >4m depth ranges. These ranges were mapped by delineating the ~1.6m and ~4m radar-interpreted isobaths.

A statistical analysis of the validity and accuracy of these interpreted depths was made through repeated radar interpretations for 20 test lakes. The interpretation consistency was greater for the ~1.6m than for the ~4m isobath when using repetitive interpretations by a single individual and when comparing between several individuals.

After a well-trained individual interpreted depths on all 12 quadrangles, fathometer transects were acquired on 157 field verification lakes for statistical comparison with radar-interpreted lake dephs. Lakes depicting the ~1.6m radar-interpreted isobath were verified in 99 percent of the 109 test lakes sounded by fathometer. Mean horizontal displacement of the confirmed ~1.6m radar isobaths from the fathometer-determined 1.6m depth was 62m (predominantly shoreward). Lakes with interpreted depths greater than ~4m were verified in only 63 percent of the 27 test lakes sounded by fathometer. Mean horizontal displacement of the confirmed ~4m radar-interpreted isobaths from the fathometer-determined 4m depth was 147m.

Sequential radar images with good resolution taken within a single season might become available in the future and would provide a basis for refined interpretation of arctic lake depths.

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INTRODUCTION TO MAPPING RADAR-INTERPRETED DEPTHS

Objectives

This report summarizes efforts to depict and verify radar interpreted lake depths on 12 maps (Mellor, 1985) covering the National Petroleum Reserve in Alaska (see Figure 1). Field verification efforts were concentrated in the Arctic Coastal Plain because this area has the greatest density of lakes. Efforts were less intensive for foothills lakes near the Brooks Range.

The primary objective was to test the applicability of an interpretation method that used Side Looking Airborne Radar (SLAR) images. This required a regional data base of sufficient proportion for statistical analysis. A second objective was to obtain new lake depth data that could be used for environmental analysis. Resulting lake isobaths are available on the 12 Geological Survey maps.

In this paper, the radar interpreted isobaths (i.e. approximately 1.6m and 4m) will be referred to as the 1.6m or 4m radar isobath. The reader can assume the presence of the words "interpreted " and "approximately" remembering that these "radar isobaths" are only interpretative results.

Prior Research

Although SLAR imagery along the Alaskan arctic coast was acquired in the 1970's primarily for offshore purposes, the data also led to onshore findings. Many investigators reported unique SLAR backscatter from arctic lakes (Sellmann et al. 1975; Elachi et al. 1976, Weeks et al. 1977 and 1978, Arcone et al. 1979). The uniquely bright SLAR signatures were from portions of lakes that had water beneath the ice cover.

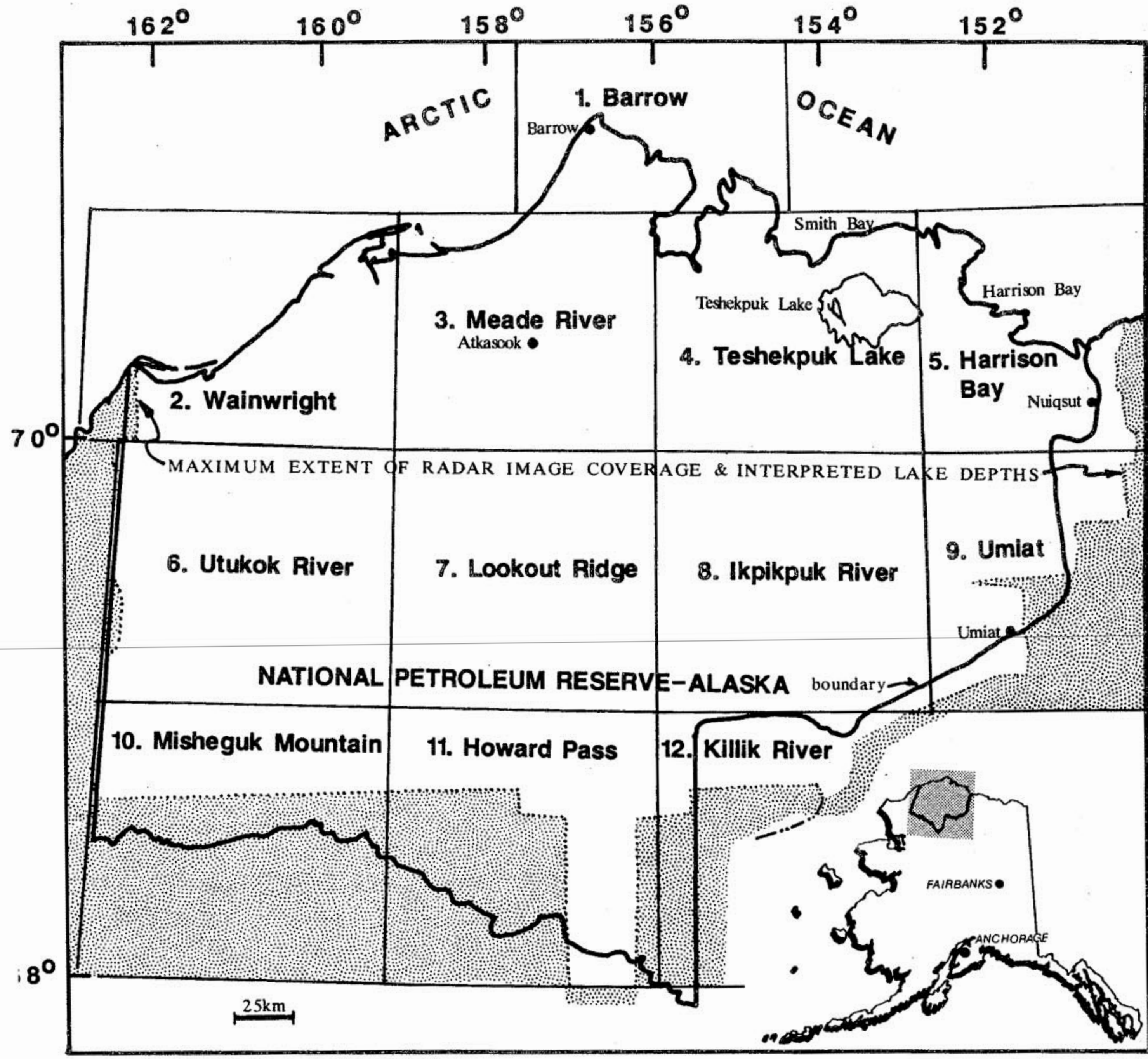


Fig. 1 Location map depicting quadrangles and limit of radar-image interpreted lake depths

Simultaneous acquisition of SLAR images and ice thickness data were used to determine the 1.6m radar isobath. SLAR images gradually changed from black along the shore to white in the lake center. Ice contact with lake bottom (1.6m isobath) is where the SLAR image changes from black along the shore to white in the lake center (Figure 2, top). Sequential SLAR images coupled with ice thickness data can be used to determine multiple lake isobaths (Mellor, 1982a and 1982b) down to maximum ice thickness (2m). Figure 2 also shows the subtle and gradual changes from white to a grayish signature, indicating the possibility of depths greater than 4m in the centers of some lakes.

This deeper isobath (between three and six meters) can also be interpreted from SLAR images. (Mellor 1982b and 1983).

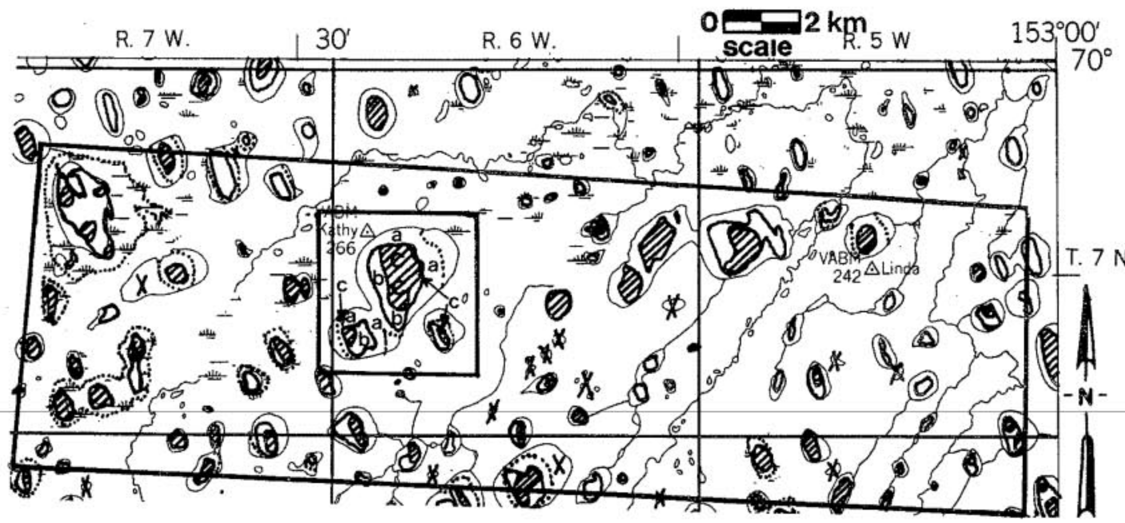
April is the best time to obtain X-band SLAR images for determining regional lake depths in the Alaskan arctic because there is little or no water near the ice surface to absorb or weaken the backscatter signal. Also, maximum winter ice thicknesses occur in April in the foothills and early May along the arctic coast.

SLAR images for this study were taken by the U.S. Army from April 7-11, 1980, for approximately 90 percent of the National Petroleum Reserve in Alaska (NPR-A) (Figure 3). These images limit the geographic extent to which lake depths were interpreted on the 12 quadrangles (Figure 1).

Synoptic lake data for this same region were collected insitu at 19 lake stations from April 6-15, 1980 (Figure 4). These data (Table 1) were collected primarily to determine approximate ice thicknesses throughout NPR-A (Figure 5) for the time during which the SLAR imagery was acquired.

The mean ice thickness was determined to be 1.6m. This was assumed to be the approximate depth at which the bottom of the ice sheets intercepted each lake bottom (Figure 6, bottom). This contact zone corresponds to the 1.6m isobath interpreted from SLAR images. Coastal lakes north of the the mid-coastal plain might have had thicker ice sheets (deeper isobaths) and foothill lakes to the south might have had thinner ice sheets (shallower isobaths) than the standard 1.6m used for interpretation. This mean ice thickness was used consistently as the basis for the 1.6m isobath mapping throughout all 12 quadrangles.

The 4m isobath was more difficult to determine and lacked precision. The SLAR signature change evidenced by the imaged gray tones over water deeper than 4m is very



KEY

Symbols in Squares Above	Description of Interpreted Depths
(a)	Water areas shallower than maximum 1980 ice thickness (0 to 1.6m deep)
(b)	Water areas deeper than maximum 1980 ice thickness (1.5 to 4.0m deep)
(c)	Water areas deeper than approximately 4 meters (≥ 4.0m deep)

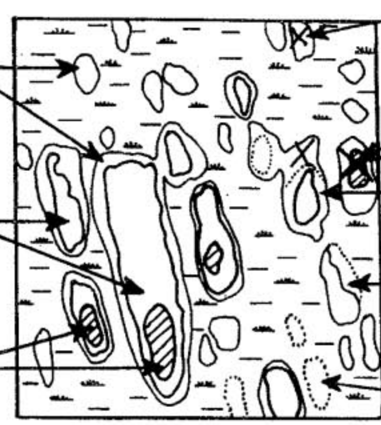


Fig. 2 Example of SLAR image (top) relative to the map product generated (middle) with key to interpreted depths/basins (bottom)

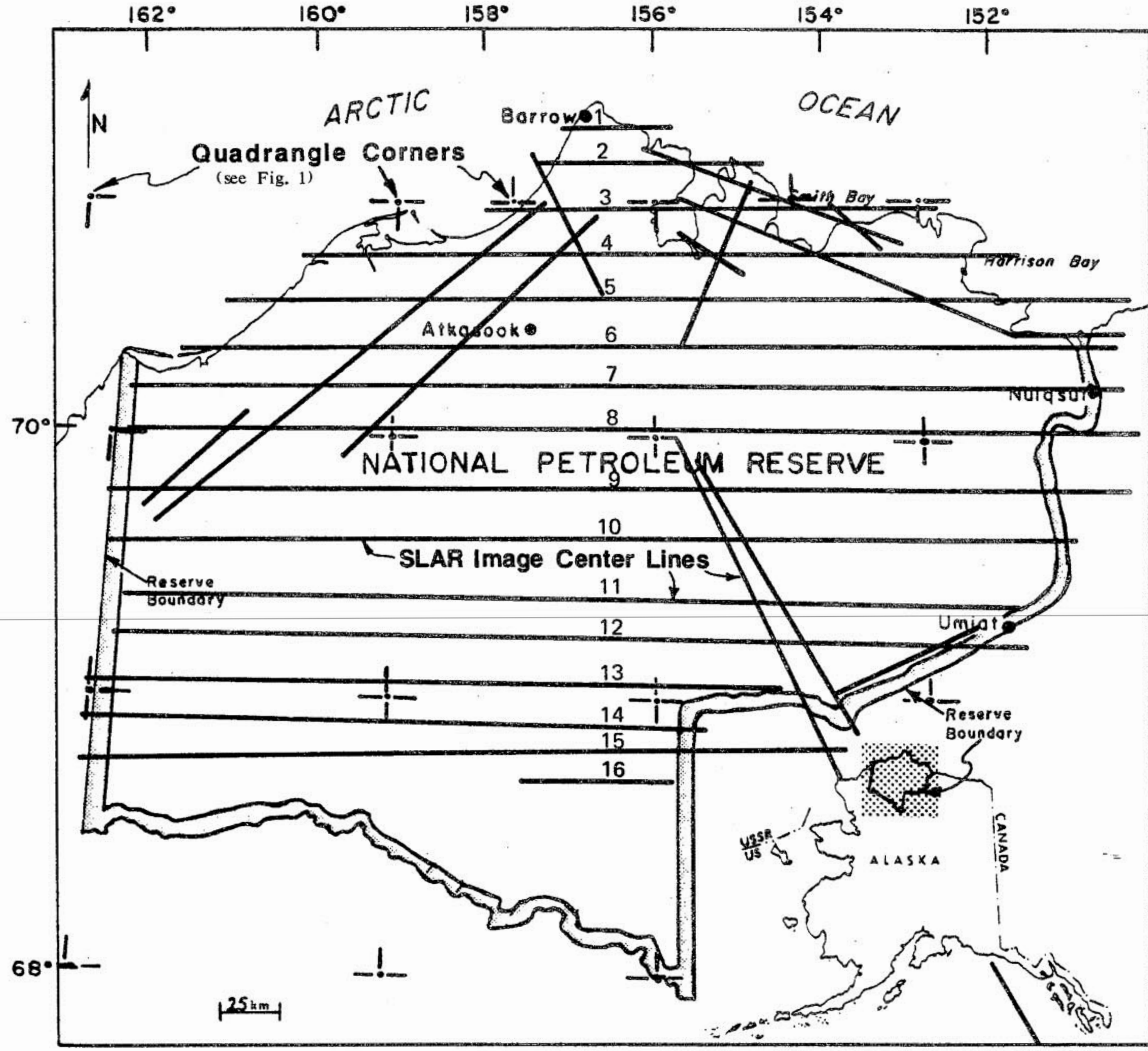


Fig. 3 April 1980 SLAR image coverage (image center lines)

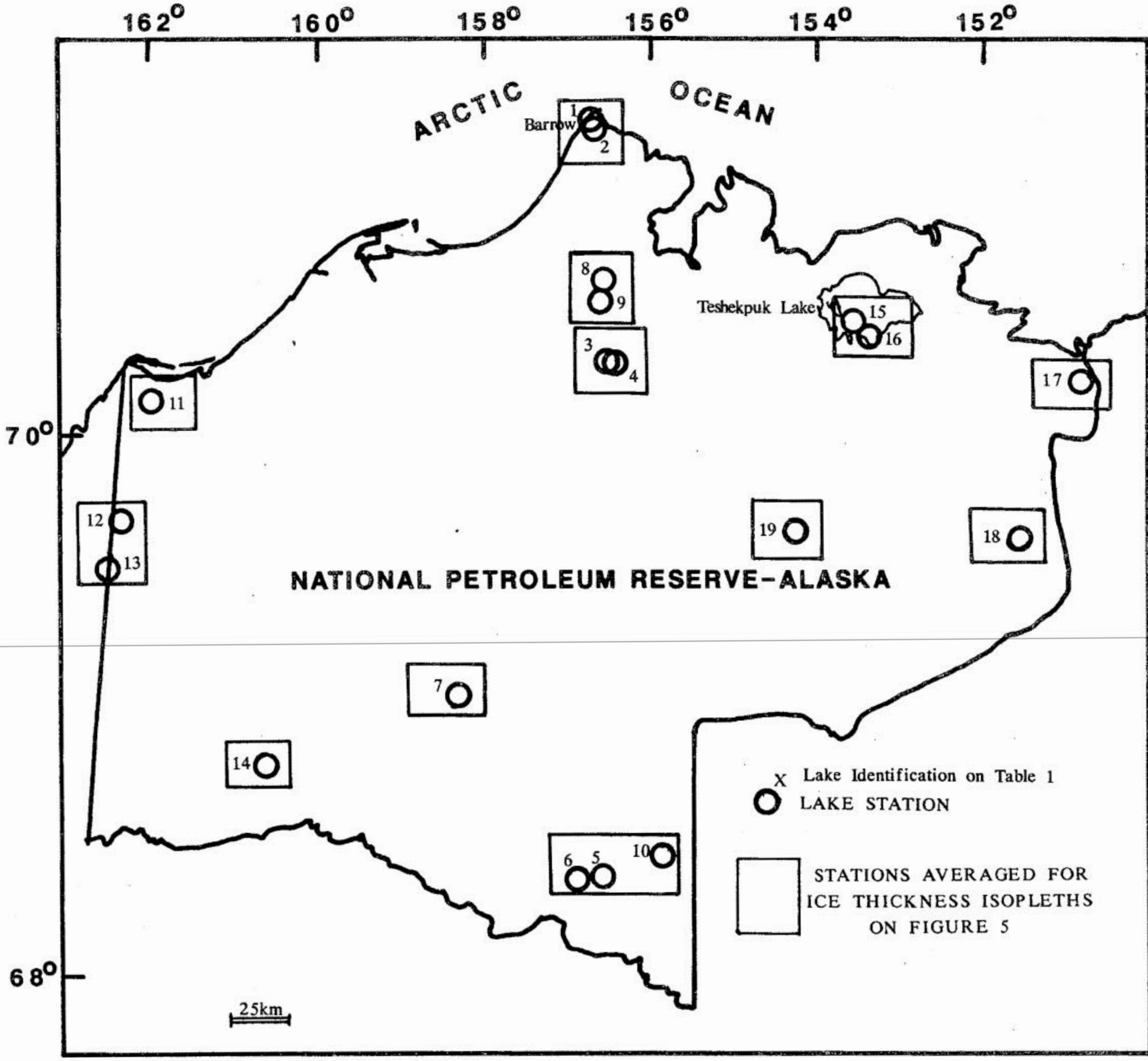


Fig. 4 Lakes sampled 6-15 April 1980 with stations averaged for regional ice thicknesses. (see Table 1 for data collected with locations)

Lake Identification	Date Sampled April '80	Latitude	Longitude	Dissolved Oxygen (ml/l) *I/W	Dissolved Oxygen (ml/l) **W/S	Temperature (°C) *I/W	Temperature (°C) **W/S	Specific Conductance (μmhos)	Chlorophyll a in water column (mg/m^3)	NUTRIENTS ($\mu gat/l$ = $\mu mole/l$) NH_3	NO_2^- + NO_3^-	NO_2^-	PO_4
1. (A-1) Imikpuk	15	71°20.2'	156°39.1'	2.1	1.8	0.1	0.1	2310	2.1 & 17.9	33.1 & 28.7	3.2 & 4.8	0.42 & 0.37	0.35 & 0.15
2. (A-2) Ikroavik	7	71°13.9'	156°37.9'	-	-	-	-	624	0.2	16.8	8.1	2.48	0.20
3. (B-1)	8	70°22.9'	156°23.4'	3.3	1.9	0.5	2.0	328	1.2	1.1	14.0	0.27	2.65
4. (B-2)	8	70°23.2'	156°28.0'	0.9	0.8	0.5	0.5	320	3.2	25.0	0.3	0.46	0.85
5. (C-1) Betty	8	68°28.6'	156°29.5'	8.5	1.5	0	2.7	70	2.8	1.4	10.2	0.35	1.15
6. (C-2)	14	68°27.9'	156°44.5'	4.5	4.5	0.6	0.6	72	1.4	3.9	29.3	1.29	3.20
7. Awuna	6	69°08.5'	158°08.5'	-	-	-	-	-	-	-	-	-	-
8. (SLAR 1)	12	70°42.5'	156°31'	5.2	5.2	0.4	0.4	580	1.6	17.4	7.5	0.35	0.10
9. (SLAR 3)	12	70°37'	156°34'	1.0	1.0	0.1	0.1	1078	4.6	126.8	0.4	0.94	0.35
10. Ivotuk	14	68°33'	156°01.5'	8.1	2.5	0.8	3.0	57	-	-	-	-	-
11. Sikolik	9	70°10'	161°29'	8.1	8.1	0.3	0.3	457	3.2	0.8	12.9	0.25	0.30
12. #92	10	69°43'	161°49.5'	5.6	5.6	0.7	0.7	330	0.7	0.7	2.1	0.29	0.45
13. #92 South	10	69°32'	161°54'	0.9	0.8	0.8	0.5	475	1.9	4.6	3.8	0.37	1.40
14. No Luck	10	68°47.5'	160°00'	0.8	0.6	0.5	0.5	326	1.2	2.4	19.3	0.52	3.40
15. Teshekpuk 1	13	70°33'	153°43'	12.3	10.5	0.1	1.6	357	1.6	0.4	2.4	0.06	0.35
16. Teshekpuk 2	13	70°29'	153°30'	12.4	8.8	0.2	1.7	447	1.2	0.5	3.2	0.19	0.65
17. Oil Lake South	13	70°16.5'	151°08.5'	0.9	0.7	0.2	0.3	1150	1.2	32.5	2.6	0.37	0.50
18. #284	13	69°42.2'	151°58.5'	0.9	0.5	0.5	2.2	487	-	-	-	-	-
19. Kokuktak	14	69°46'	154°26'	2.4	0.8	0.2	2.4	522	1.6	2.5	8.0	0.89	2.90
				4.6 Av.	3.3 Av.	0.4 Av.	1.2 Av.	555 Av.	2.8 Av.	17.6 Av.	7.8 Av.	0.58 Av.	1.11 Av.

Lake Identification	SUMMARIZED SNOW, ICE AND WATER DEPTH MEASUREMENTS Snow Thickness (cm) Av.	Snow Thickness (cm) Rg.	Av. Free-Board (cm)	Av. Overice (cm)	Max. Water Depth (m)	Ice Thickness (cm) Av.	Ice Thickness (cm) Rg.	No. of Holes	% Snow Cover
1. (A-1) Imikpuk	10	0-21	10	20	2.8	190	167-210	5	98
2. (A-2) Ikroavik	29	26-33	4	0	2.3	146	142-153	4	100
3. (B-1)	15	14-16	6	0	6.2	156	153-160	4	99
4. (B-2)	27	22-32	4	0	2.0	144	143-145	2	100
5. (C-1) Betty	10	9-12	11	12	5.6	170	156-179	4	100
6. (C-2)	30	26-36	2	13	1.8	132	131-133	4	100
7. Awuna	-	-	-	0	2.2	130	-	1	-
8. (SLAR 1)	19	14-25	8	2	2.0	156	150-161	3	100
9. (SLAR 3)	32	-	0	0	1.6	142	-	1	100
10. Ivotuk	3	-	8	0	10.0	138	135-140	2	-
11. Sikolik	20	17-22	5	5	2.0	164	156-172	2	95
12. #92	28	20-40	3	0	2.0	130	117-137	3	99
13. #92 South	17	8-36	10	0	2.0	148	136-155	3	99
14. No Luck	8	0-15	12	12	2.5	159	140-169	4	90
15. Teshekpuk 1	20	17-24	10	12	5.6	178	172-183	2	75
16. Teshekpuk 2	21	18-24	4	0	4.0	156	150-162	3	-
17. Oil Lake South	19	14-25	7	3	2.1	154	145-162	3	100
18. #284	26	22-30	5	5	3.4	141	122-154	3	100
19. Kokuktak	15	12-17	12	5	3.4	167	162-173	3	100
	19 Av.	0-40 Rg.	8 Av.	5 Av.	3.3 Av.	153 Av.	117-210 Av.	56 Total	97 Av.

* I/W = Ice/water interface
**W/S = Water/substrate interface

Table 1 Lake data sampled, 6-15 April 1980

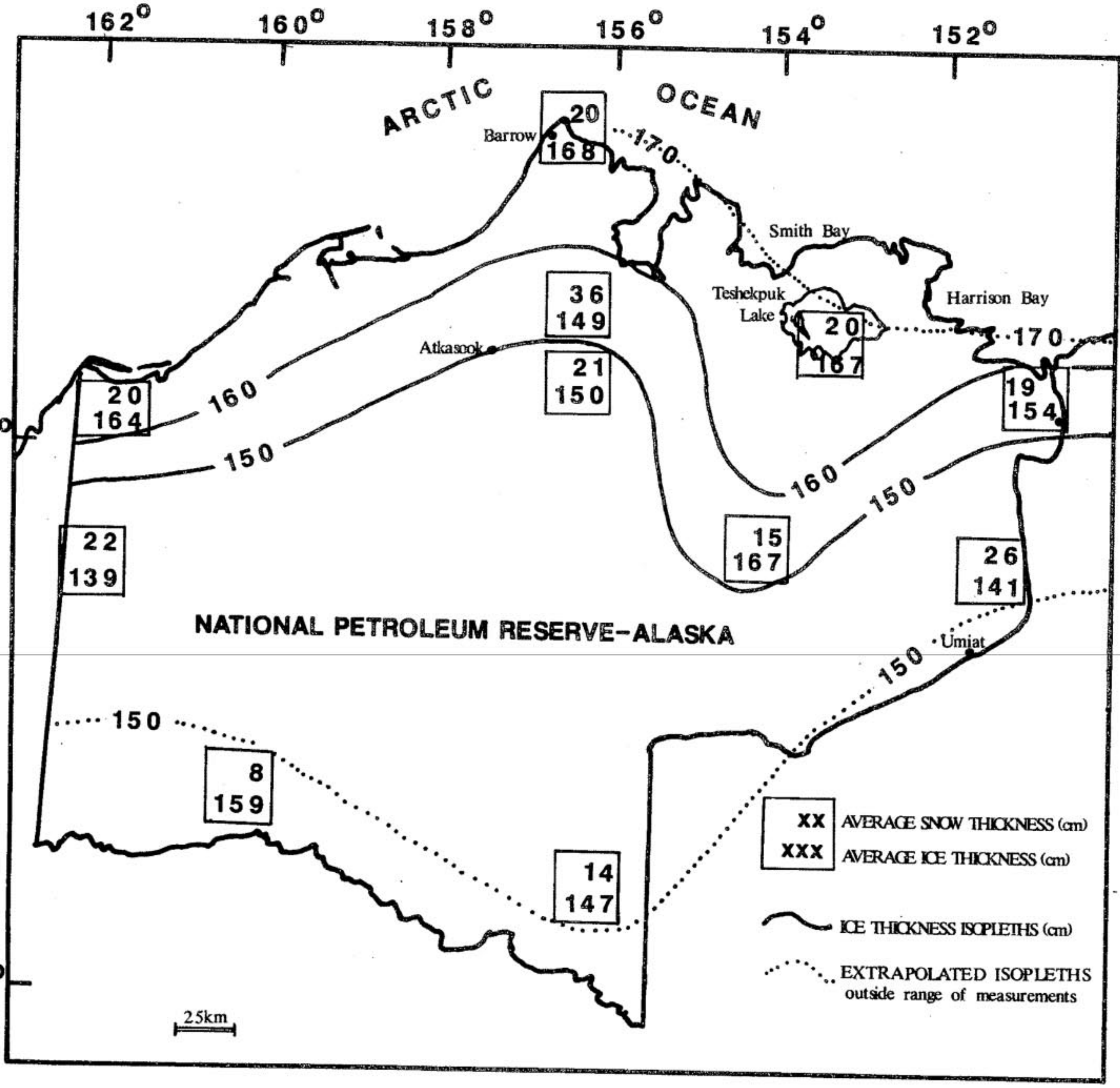


Fig. 5 Ice thickness isopleths for 6-15 April 1980

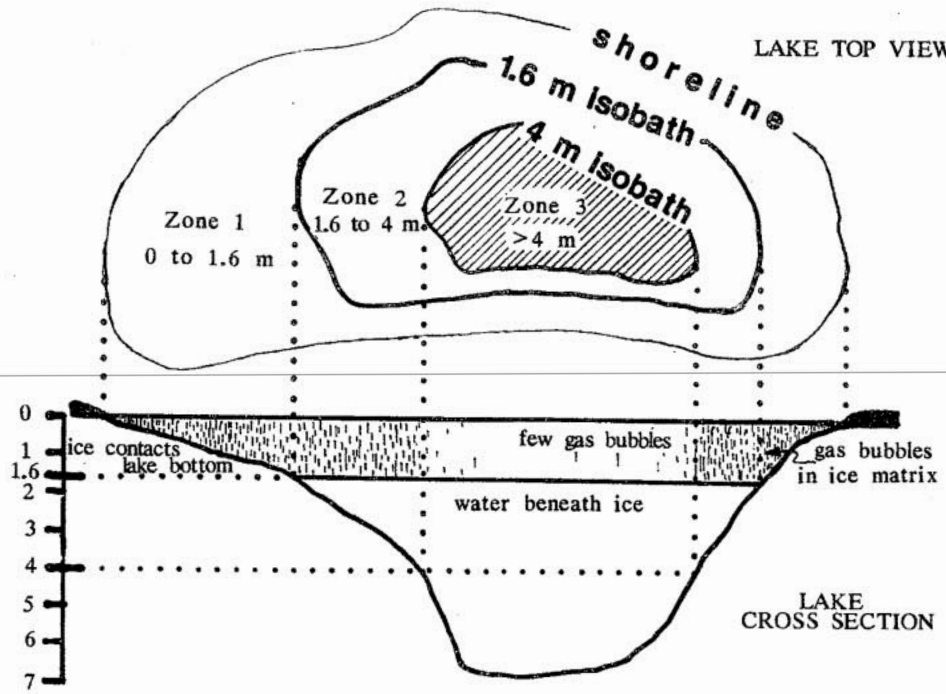


Fig. 6 Lake cross-section illustrating ice cover and ice depth relative to isobaths mapped from radar

subtle (Mellor 1983) (*1). The image signature on the April 1980 data set (e.g. Table 1: lakes 3, 5, 10 and 15) and other lakes with known depths exceeding 3m were compared to the subtle tonal changes seen on the SLAR images. The image change seemed to be discernible at depths varying from 3 to 6 meters. The change in gray tones seemed to be most evident at about the 4m lake depth (which was used as the second radar isobath).

Unfortunately, darker gray tones also appear in the center of shallow lakes that have brackish water greater than two parts per thousand under the ice cover. Brackish rather than deep water beneath the ice cover can also be responsible for the image tone variations. Therefore, brackish lakes within 30km of the Arctic Ocean were erroneously interpreted as 4m or deeper when they were actually shallow.

The interpretations were made as consistently as possible on all 12 quadrangles where a change in tones was discernible. Lake verification data and statistical analyses confirmed that lakes within 30km of the Arctic Ocean depicting mapped depths greater than 4m, were for the most part, in error.

Quadrangle isobaths have been left as interpreted and have been analyzed statistically as mapped, but those lakes with 4m radar isobaths that were probably mapped in error have X's drawn through their questionable 4m deeps. This error occurs primarily in the Teshekpuk Lake Quadrangle, but also occurs to some extent in other coastal quadrangles such as Barrow, Harrison Bay, Meade River and Wainwright. Erroneous 4m isobaths and cross-hatching could have been removed from those misinterpreted lakes to create cleaner maps, but the data would then have had less interpretation testing utility.

(*1) The difference in radar backscatter is probably related to the number of bubbles trapped in the ice matrix (Mellor, 1982b). Fewer bubbles occur in ice over deep water than over shallow water (Figure 6). Large numbers of bubbles provide for radar backscatter and the white image signature over shallow depths (1.6m-4m). Fewer bubbles cause less backscatter and a subtle change in image signature from white to gray over lake areas greater than 4m deep.

Radar Isobaths Mapped on 12 Quadrangles

Differences in SLAR backscatter from lake ice cause tonal variations (Figure 2, top). Depths less than 1.6m have a weak radar backscatter (dark image); areas greater than 1.6m and less than 4m have a strong backscatter (white image); and areas greater than 4m have a moderate backscatter (gray image).

Although lake radar isobaths were interpreted from SLAR imagery, aerial photographs available for approximately 95 percent of the study lakes provided additional lake basin data. A comparison between the original 1955 quadrangles with the 1975-1979 aerial photographs indicated changes in shorelines and lake basin size and shape. Some basins were completely drained. The photographs were used to update shorelines (dotted lines on lakes mapped, Figure 2). Landsat satellite color composites provided a similar but less accurate aid where aerial photographs were absent.

Reproductions of U.S.G.S. quadrangle overlays were printed on clear acetate to allow registration to SLAR image prints, both of which were at 1:250,000 scale.

Interpreted isobaths then were drawn on quadrangle overlays. The outside of the pen line ("00" rapidiograph) represents the best possible manual interpretation of an isobath, often obtained from SLAR images of poor quality. One individual did all interpretations after a learning/testing period to develop consistency.

The 1.6m isobath interpretation is distinct, but the 4m interpretation is subtle and leaves considerable room for subjective placement. Areas where lake isobaths had been mapped from fathometer transects were compared to initial/practice SLAR interpretations. Once consistency and confidence were achieved, more than twenty thousand lakes were interpreted within a few weeks.

Those lakes interpreted to be totally frozen were so shallow that no isobaths were drawn. Those lakes with both 1.6m and 4m isobaths were few in number but took the majority of time. This effort was completed during the summer of 1982.

Publication of the 12 quadrangles was delayed until 1986 while statistical verification of data reliability was determined.

STATISTICAL ANALYSES

Objectives

Two methods of statistical comparison were chosen to test the reliability of interpretation theory and mapping methodology.

In the first method, fathometer depths from verification lakes were compared to the interpreted depths. The second method used a common set of SLAR-image test lakes to compare consistency of (a) multiple interpretations of the same lake by a single interpreter and (b) interpretations of the same lake by different interpreters.

Statistical analyses of fathometer versus radar-interpreted depth comparisons have been summarized on each of the 12 quadrangles. These are meant to generally quantify interpretation and mapping accuracies on each map for the map user. This report consolidates mapping and statistical analysis for the entire data set.

Twelve grid systems were non-randomly superimposed on 12 quadrangles (Figure 7). Then lakes were chosen within grids using computer-generated random numbers.

Grid set A1-5 was uniformly distributed across northern coastal plain lakes. Set B1-5 was placed over the mid-coastal plain lakes. The last two grid systems were superimposed on areas with lake concentrations in the foothills of the Brooks Range.

The 12 grids are within eight of the 12 quadrangles (Figure 7). The four unsampled quadrangles are in foothills areas lacking dense concentrations of lakes.

The following verification results are meant to provide a better regional understanding of: radar-interpreted isobath mapping difficulties; probable isobath displacements; and appropriateness of the 1.6m and 4m isobath depth labels.

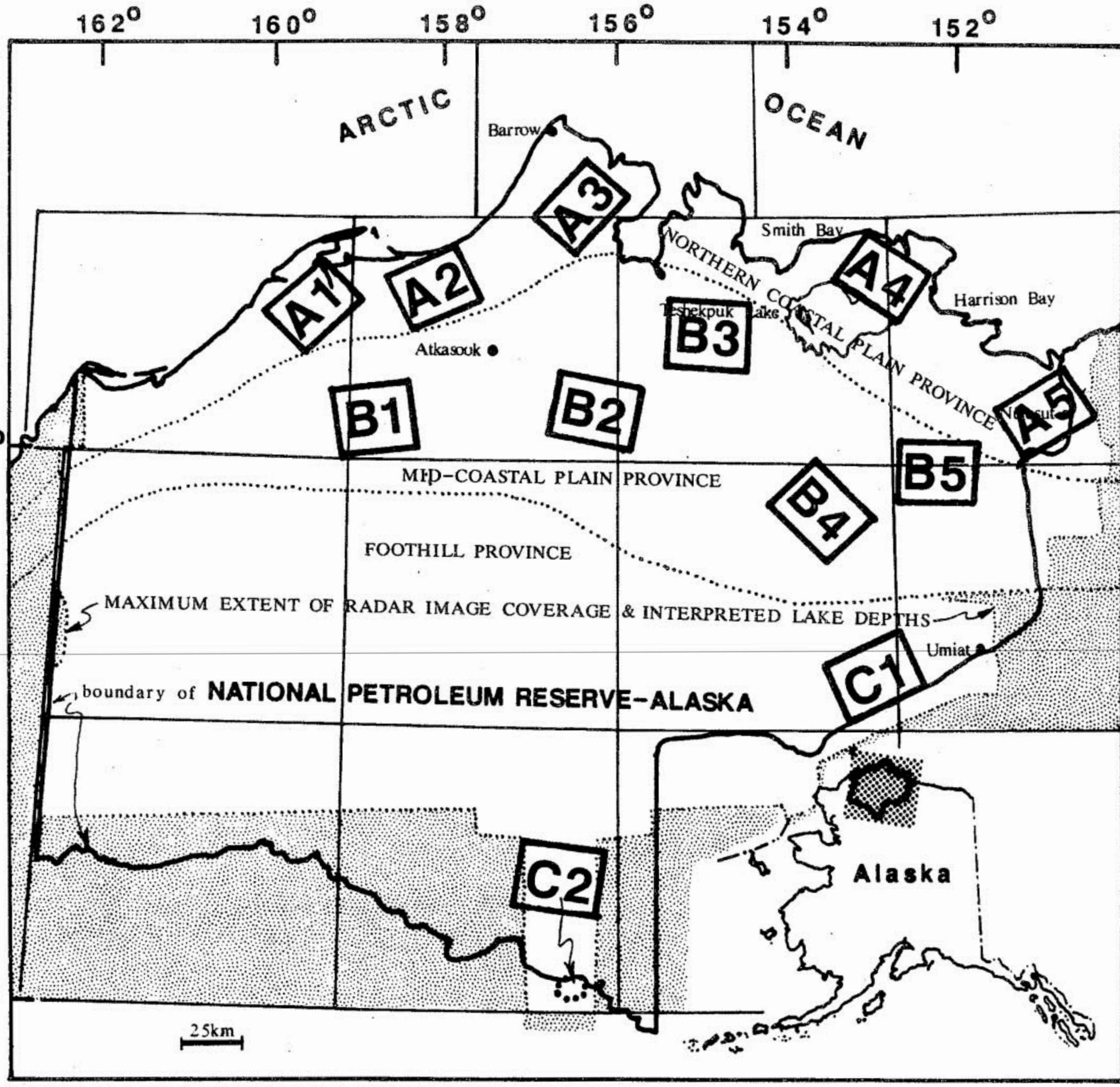


Fig. 7 Lake verification grid placement

Field Verification with Fathometer Transect Depths

1. Methods

During the summer of 1983, water depths on 157 lakes were obtained with a fathometer for comparison with their radar-interpreted depths. Two to five continuous depth recording transects were taken on each lake. Transects bisected each lake in an attempt to cross the deepest portion to define overall basin bathymetry with as few transects as possible.

The presence or absence of the 1.6m and 4m radar isobaths were analyzed relative to two ranges of fathometer depths such as 1.3 to 1.8m and 3 to 6m. Displacement measurements were made from radar-interpreted isobaths (e.g. 1.6m and 4m) to discrete fathometer depths (i.e. 1.3, 1.6, 1.8m and 3, 4, 6m) along each lake transect (Figure 8).

The 1.6m radar isobath was verified with a 0.5m range of fathometer depths (Table 2) that approximated the range of April 1980 lake ice thicknesses measured near the verification lakes. For example, if a fathometer depth between 1.3m and 1.8m existed for a lake in the Meade River quadrangle (i.e. grid A-2), the presence of the 1.6m radar isobath was confirmed.

Similarly, an A-2 lake lacking a 1.6m radar isobath would be confirmed if none of the fathometer transects had a depth greater than 1.8m. The 4m radar isobath was treated in the same manner, but the confirming fathometer depth range in all quadrangles and grids was 3m to 6m. Poor quality images, varying lake conditions and subtle image tonal changes for the 4m isobath interpretation dictated the need for the 3m range of fathometer depths (3m to 6m). The fathometer obviously provided a more definitive bathymetric measure than the 4m radar isobath.

Measurements were made to compare the spatial differences between radar and fathometer isobaths. These measurements were the closest distance between three discrete depths (3, 4 and 6m) and the radar isobath (4m). For analysis, all displacement errors were segregated into those contrasting toward shore versus toward lake center. This analysis tested the appropriateness of radar isobaths assumed to be 1.6m and 4m. Such analysis could indicate the need to adjust the 1.6m isobath depth which was approximated from regional ice thicknesses/depth ranges, and the 4m isobath depth associated with lake areas having an ice matrix containing few gas bubbles.

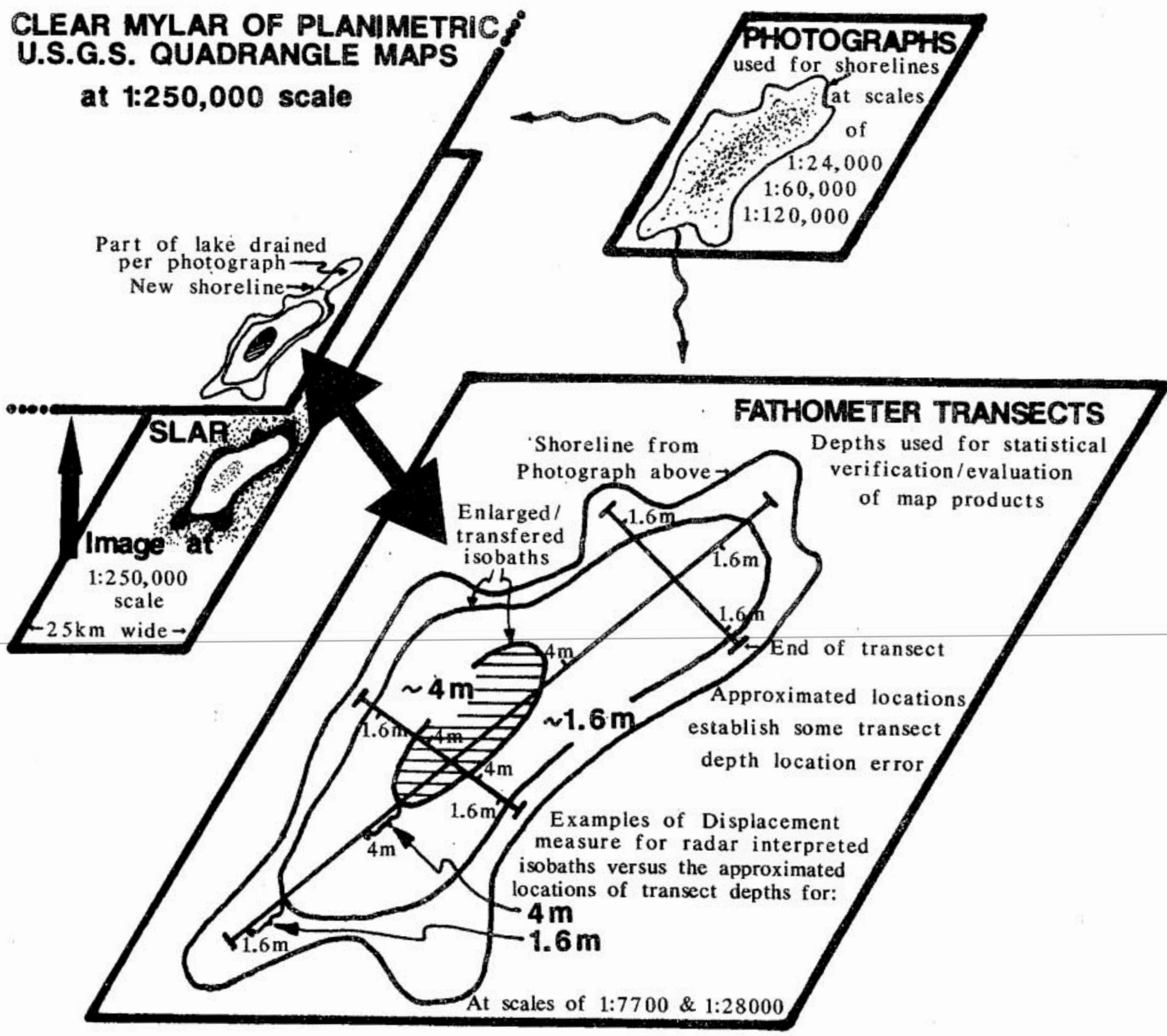


Fig. 8 Illustrated methods for comparison between radar-interpreted isobaths and fathometer transects

Table 2 Depth ranges (viz. ~1.6m ice thickness and ~4m change in radar image gray tone) and verification grids used by quadrangle

NO. QUADRANGLE	0.5m DEPTH RANGE COMPARED WITH THE 1.6m RII*	3m DEPTH RANGE COMPARED WITH THE 4m RII*	VERIFICATION GRIDS IN PROXIMITY TO QUADRANGLE USED FOR STATISTACAL ANALYSIS
1. BARROW	1.4 to 1.9m	3 to 6m	A-3
2. Wainwright	1.3 to 1.8m	3 to 6m	A-1, B-1, A-2
3. Meade River	1.3 to 1.8m	3 to 6m	A-2, B-1,2, A-1,3
4. Teshekpuk Lake	1.3 to 1.8m	3 to 6m	A-3,4, B-2,3,4,5
5. Harrison Bay	1.3 to 1.8m	3 to 6m	A-4,5, B-5
6. Utukok River	1.2 to 1.7m	3 to 6m	B-1
7. Lookout Ridge	1.2 to 1.7m	3 to 6m	B-1,2, C-2
8. Ikpikpuk River	1.2 to 1.7m	3 to 6m	B-4,5, C-1
9. Umiat	1.2 to 1.7m	3 to 6m	A-5, B-4,5, C-1
10. Misheguk Mt.	1.2 to 1.7m	3.to 6m	C-1,2
11. Howard Pass	1.2 to 1.7m	3.to 6m	C-1,2
12. Killik River	1.2 to 1.7m	3 to 6m	C-1,2

* RII = Radar Interpreted Isobath

Results

Although fathometer transect positioning was not precise, a worst-case field estimate of location was plus or minus 100m. Chart-to-map data transfer and comparative measurement inaccuracies were of about the same magnitude.

Isobath verification by field fathometer measurement is limited by inherent inaccuracies which must be taken into account when comparing these with radar isobaths. Areal location of fathomer transects was of varying difficulty (Figure 8) depending on lake size and decernable reference points on shore. This produced a corresponding set of fathometer depth inaccuracies which could not be assessed, but need to be considered when comparing with the radar isobaths. Since all original radar-interpreted isobaths were mapped at 1:250,000 scale, errors could be introduced when the information was transferred to a larger scale for comparison with fathometer depths.

Table 3 (*2) is a summary of statistical analyses selected to compare radar isobaths with lake depths determined by fathometer transects. This data set includes almost 400 transects on 157 lakes sampled within the 12 sampling grids.(*3) Each transect was scanned for six depths (i.e. 1.3, 1.6, 1.8, 3, 4, and 6m). The majority of verification lakes were less than 6m deep, and many were less than 1.3m deep. Shallow and small lake basins were difficult and dangerous to sample by float plane, limiting some shallow lake basin verification data.

Forty-eight of the 157 test lakes were interpreted as not having the 1.6m radar isobath; 92 percent of those were confirmed by fathometer transect. A total of 109 lakes had the 1.6m radar isobath with 99 percent of those confirmed. Only 27 lakes had a 4m radar isobath, and only 63 percent of those were verified by fathometer. Figure 9 illustrates this comparison of isobath interpretation with fathometer data for each case where presence or absence of the 1.6m or 4m isobath could be verified. (*4)

(*2) Table 3 summarizes only a few of the most relevant and least voluminous statistical analyses performed. Refer to Figure 6 for illustration of the radar interpreted isobaths and intervening zones identified in Table 3 headings.

(*3) The number of lakes or displacement measurements (frequency) used in each analysis is reduced substantially by some of the areal (number of lakes in grid(s) sampled) and depth subsets depicted in Table 3.

(*4) The entire data set of 12 quadrangles and 157 verification lakes is shown at the top of Table 3.

① RII = Radar Interpreted Isobath
② FD = Fathometer Depths
③ A = Absent
④ P = Present
⑤ w/o = Without

Table 3 Statistical results summarized for absence of or presence and displacement of radar-interpreted isobaths compared with fathometer transect depths

			PRESENCE/ABSENCE								DISPLACEMENT OF CONFIRMED					
			Lakes w/o ~1.6m RII CONFIRMED by FD <1.9m (Zone II A)		Lakes w/o ~4m RII: with ~1.6m RII CONFIRMED by FD >1.2 & <6m (Zone II P)		Lakes w/o ~4m RII: with or w/o ~1.6 RII CONFIRMED by FD >0m & <6m (Zone II P or A)		Lakes with ~4m RII CONFIRMED by FD ≥3m (Zones I, II, & III P)		~1.6m RII from FD of 1.6m			~4m RII from FD of 4m		
DATA SET: Geographic Area Represented	# of Grid Areas Sampled	# of Lakes Sampled	# of Lakes w/o ~1.6m RII	% Verified by FD	# of Lakes w/o ~4m RII & with ~1.6m RII	% Verified by FD	# of Lakes w/o ~4m RII & with or w/o ~1.6m RII	% Verified by FD	# of Lakes with ~4m RII	% Verified by FD	Mean (m)	Total Frequency	1 Std. Deviation (m)	Mean (m)	Total Frequency	1 Std. Deviation (m)
ENTIRE DATA SET All verification lakes in: all regions, 12 grid areas, and 12 USGS quadrangles	12	157	48	92%	109	99%	130	98%	27	63%	62m	531	101m	147m	58	137m
REGIONS (PROVINCES)																
Northern Coastal Plain (A - Grid Areas)	5	80	40	95%	39	97%	73	100%	7	28%	73m	154	140m	-	0	-
Mid-Coastal Plain (B - Grid Areas)	5	64	4	75	60	100	48	96	19	74	62	315	82	147m	56	140m
Foothills (C - Grid Areas)	2	13	3	67	10	100	12	92	1	100	38	62	56	152	2	61
USGS QUADRANGLES (1:250,000 scale)																
Barrow	1	16	12	92%	4	100%	13	100%	3	0%	41m	14	43m	-	0	-
Wainwright	3	39	16	94	23	96	39	100	0	-	103	68	131	-	0	-
Meade River	5	68	29	93	39	97	63	100	5	0	82	152	104	147m	58	137m
Teshekpuk Lake	6	91	24	96	67	100	65	97	26	62	58	347	78	139	55	129
Harrison Bay	3	46	16	94	30	100	37	97	9	56	53	148	114	135	8	87
Utukok River	1	8	2	50	6	50	8	100	0	-	66	20	68	-	0	-
Lookout Ridge	3	26	4	75	22	100	23	96	3	33	57	118	70	152	2	61
Ikpikpuk River	3	33	3	67	30	100	18	94	15	80	70	153	99	142	44	136
Umiat	4	47	8	75	39	100	32	97	15	80	69	207	126	142	44	136
Misheguk Mountain	2	13	3	67	10	100	12	92	1	100	38	62	56	152	2	61
Howard Pass	2	13	3	67	10	100	12	92	1	100	38	62	56	152	2	61
Killik River	2	13	3	67	10	100	12	92	1	100	38	62	56	152	2	61
LAKE VERIFICATION AREAS/GRIDS																
A-1	1	16	8	100%	8	88%	16	100%	0	-	134m	24	78m	-	0	-
A-2	1	15	6	100	9	100	15	100	0	-	104	24	109	-	0	-
A-3	1	16	12	92	4	100	13	100	3	0%	41	14	43	-	0	-
A-4	1	19	10	100	9	100	15	100	4	50	38	38	37	-	0	-
A-5	1	14	5	80	9	100	14	100	0	-	66	54	181	-	0	-
B-1	1	8	2	50	6	100	8	100	0	-	66	20	68	-	0	-
B-2	1	13	1	100	12	100	11	100	2	0	69	70	77	-	0	-
B-3	1	18	0	-	18	100	16	94	2	100	42	106	46	166m	12	157m
B-4	1	12	0	-	12	100	2	100	10	90	97	63	137	143	36	146
B-5	1	13	1	100	12	100	8	88	5	60	51	56	46	135	8	87
C-1	1	8	2	50	6	100	8	100	0	-	52	34	68	-	0	-
C-2	1	5	1	100	4	100	4	75	1	100	20	28	17	152	2	61
RANGES (0.5m) OF FATHOMETER DEPTH (APPROXIMATIONS FROM ICE-THICKNESSES) USED IN COMPARISON WITH RADAR INTERPRETED ISOBATHS																
1.4 to 1.9m (A-3 grid only)	1	16	12	92%	4	100%	13	100%	3	0%	41m	14	43m	-	0	-
1.3 to 1.8m (A-1,2,4,5, B-1,3,4 grids)	7	102	31	94	71	99	86	99	16	81	68	329	118	149m	48	147m
1.2 to 1.7m (B-2,5, C-1,2 grids)	4	39	5	80	34	100	31	94	8	50	53	188	63	138	10	79

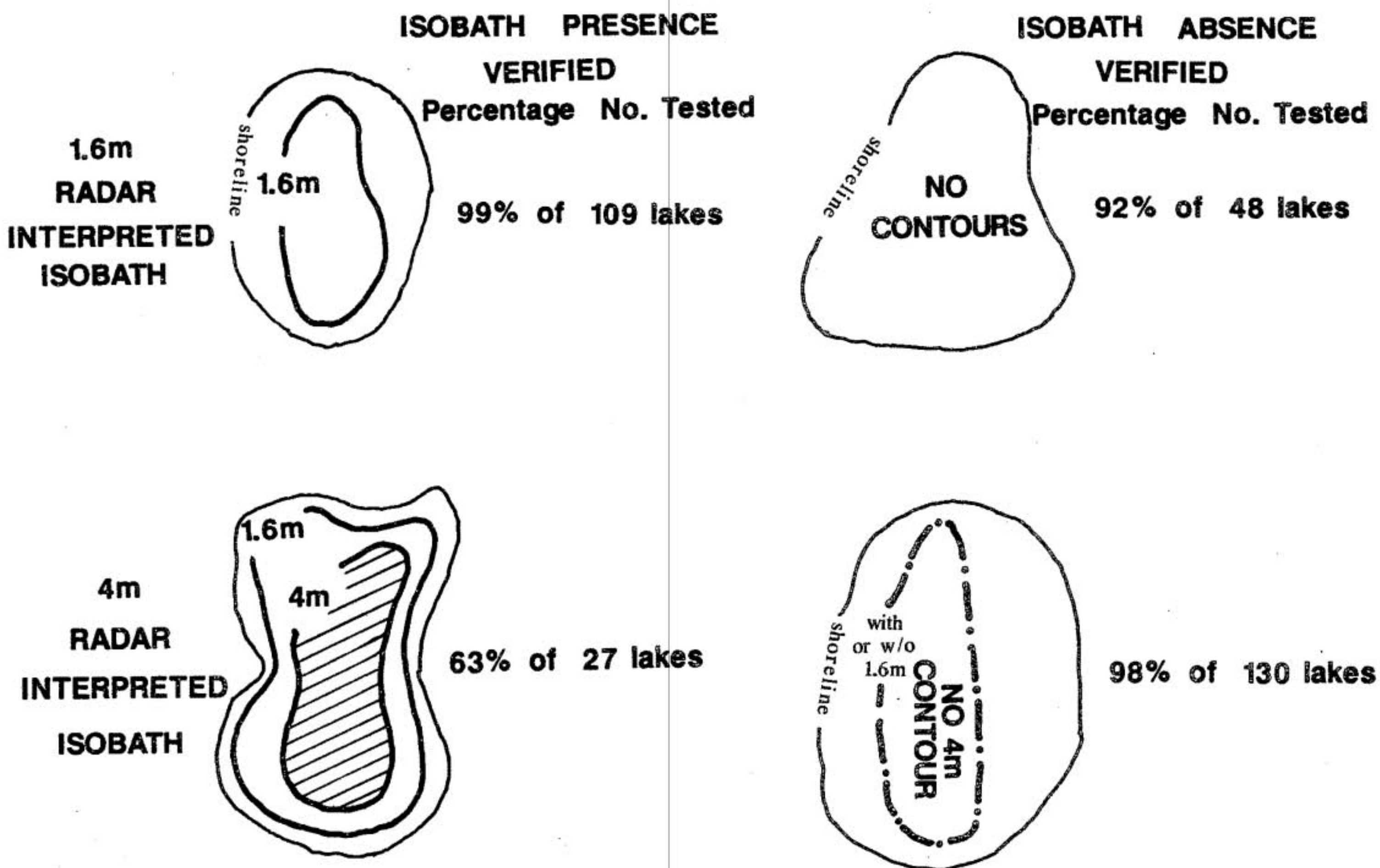


Fig. 9 Illustrated conditions for radar-interpreted isobath presence/absence with percentages of test lakes with verifying fathometer depths

Mean displacement of confirmed 1.6m radar isobaths compared to the 1.6 fathometer depth locations was 62m with one standard deviation of 101m. Similarly, mean displacement for the 4m isobath was 147m with a standard deviation of 137m.

Confirmation of radar isobaths (Table 3) was lowest in the column of percentages for fathometer confirmation of the 4m radar interpreted isobath. Most of that error occurred in the Northern Coastal Plain Province where only 28 percent of the seven lakes with a 4m isobath were confirmed by fathometer. These lakes were near the Arctic Ocean (Barrow, Teshekpuk Lake and Harrison Bay quadrangles) in grid areas A-3 and A-4. None of the three lakes with a 4m isobath in grid A-3 were confirmed, and only two of four (50 percent) were confirmed in grid A-4. Grid B-5 was also close enough to the coast to be similarly affected. Additional lakes that were not part of the statistical analyses were sampled to help determine reasons for this interpretation error.

As brackish lakes freeze down during the winter the brine concentrates beneath the ice. As the water beneath the ice approaches salinities of 2 parts-per-thousand (approximately five percent that of sea water), ice characteristics begin to change.(*5) This change in turn reduces the radar return signal strength producing a gray image tone similar to deep lake areas. This phenomenon seems to occur in a band approximately 30km wide along the coast where there are very few deep (greater than 3m) lakes.(*6)

Statistical analyses specific to each quadrangle are summarized in Table 3 and are discussed on each quadrangle.(*7)

(*5) The increase in salinity changes the bottom of the ice, making it a less discreet ice/water boundary. Water trapped withing the ice absorbes the radar signal.

(*6) Rather than change the interpretations on the quadrangles, lakes suspected of being in error (depicting an erroneous 4m radar interpreted isobath) were noted by placing an X across them.

(*7) The Utukok River, Lookout Ridge, Misheguk Mountain and Killik River quadrangles had the least lake verification data specific to their quadrangle. Less than a quarter of the Misheguk Mountain and Killik River quadrangles had radar image coverage from which to interpret lake depths (see Figure 1). Umiat and Howard Pass quadrangles had approximately 50 percent radar image/depth interpretation coverage. Some of the Table 3 data subsets (i.e. Grids B-1 and C-1, 2 and Utukok River Quadrangle) had too few verification lakes for good statistical analyses.

The last subsets include the three ranges of fathometer depths used for comparison with, and confirmation of, the 1.6m radar interpreted isobath. These ranges (shown at the bottom of Table 3) were those used to verify the 1.6m radar isobath within each of the verification grids and were chosen to bracket April 1980 ice thicknesses (Figure 5) best.

The 1.6m isobath displacements shown in Table 3 were measured from the 1.6m fathometer depths. The largest mean displacement (68m) and standard deviation (118m) occurred within the 1.3 to 1.8m range for the 1.6m radar isobaths.

Confirmation of the presence of the 4m radar-interpreted isobath was lowest (0 percent) for the three lakes sampled in the A-3 grid or Barrow Quadrangle. This resulted from the low number of lakes sampled. All three lakes were within the 30km band subject to 4m radar isobath interpretation error. The inland lakes (1.2m to 1.7m range in Table 3) had 50 percent of the eight lakes with an 4m isobath confirmed. This range incorporated deeper lakes sampled in grids B-5 and C-2. The largest number of lakes with confirmed 4m isobaths (10 lakes with 90 percent confirmation) occurred in grid B-4. This area is centered in an area with a large concentration of deep lakes.

Confirmation of absence of the 4m and presence of the 1.6m radar isobaths was generally very good (90 percent to 100 percent) as can be gleaned from Table 3. However, some difficulty occurred in confirming absence of the 1.6m isobath in the Mid-Coastal Plain (75 percent) and Foothill provinces (67 percent) where few lakes were visited. Absence of the 1.6m radar isobath was verified in 95 percent of 40 Northern Coastal Plain lakes tested.

Repetitive Laboratory Interpretations

Methods

During the summer of 1985, twenty lakes were selected from the 157 verification lakes for a repetitive interpretation test. This subset was chosen such that half of it had original radar isobaths greater than 4m. The remaining 10 lakes had the 1.6m isobath, but did not have the original 4m radar isobath. Eleven of the lakes were considered large (longest axis greater than 1km) and the remaining nine were considered small (longest axis less than 1km).

Four individuals made two different isobath interpretation attempts for each of the 20 lakes. Some training had to be provided to each of four interpreters prior to their completing the interpretations to be compared. Their level of interpretive expertise and overall understanding of the radar-interpreted isobath methods was much less than that sought for the individual that interpreted depths on the 12 quadrangles. In addition, the level of expertise and understanding varied between the four interpreters used for repetitive laboratory analyses. Sufficient training was provided to assure that each individual understood the basic lake depth/radar image theory and mapping techniques.

Analyses are divided into comparisons of presence/absence and differences in placement of an isobath. An investigator may have interpreted a 4m isobath only once out of two attempts, thereby contradicting himself.

Presence/absence data also consisted of percentages of isobaths with conflicting interpretations between individuals.

Spacial accuracy of the analysis was recorded as differences measured between successive placement of an isobath on a lake relative to fixed lake axes. The ability to physically measure the differences between successive isobaths was estimated to be plus-or-minus 25 meters. Figure 10 illustrates how isobath placement differences were evaluated using major and minor perpendicular lake axes to orient rectangles drawn tangentially to successive isobaths when overlayed. Four measurements were made from each pair of isobaths.

Results

Two hypothesis are tested. The first tests if each interpreter is as accurate and reliable as the others. The second tests if the 1.6m radar isobaths are interpreted more accurately and reliably (consistently) than were the 4m radar isobaths.

When several investigators interpreted the same radar data, each could have come to different conclusions.

Repetitive interpretation analysis, with its interpreter inconsistencies, still provided a good comparison of the relative interpretation difficulty between the 1.6m and the 4m radar isobath.

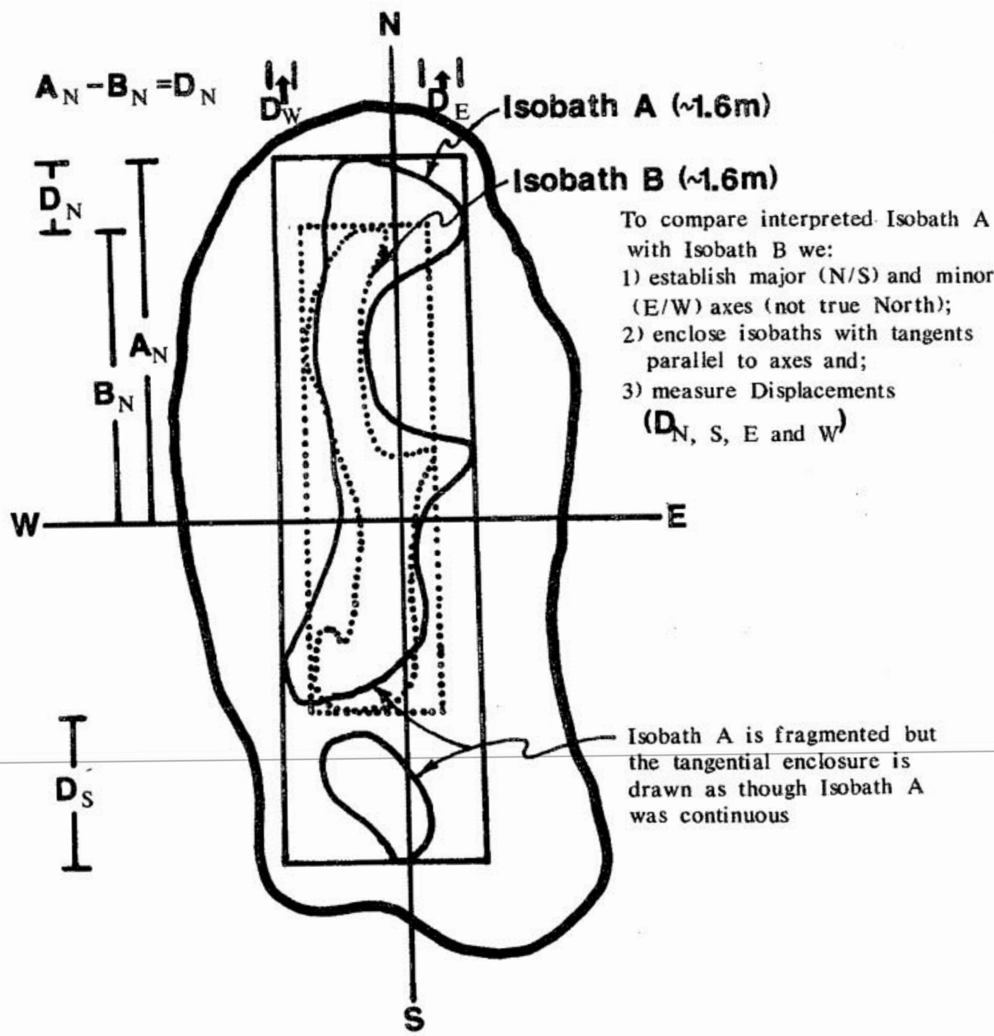


Fig. 10 Illustrated method for displacement measure between repetitive radar-interpreted isobaths

Table 4 summarizes results from 720 repetitive isobath interpretation measurements on 20 test lakes. Interpretations from five different individuals are analyzed. These data include some comparisons with original interpretations from the attached set of 12 quadrangles.

Hypothesis 1 (see Table 4)

Percentage of interpretation conflicts for all interpreters ranged from two to eight percent for personal inconsistencies. Slightly higher "between interpreter" inconsistencies ranged from 5 to 11 percent.(*8)

Mean displacement(*9) for individual interpreters ranged from 38m to 78m. The largest standard deviation was 165m. These measurements are consistent with and are within the same range of reliability as comparisons between radar isobaths and fathometer depths.

The first hypothesis was accepted for only three of the four interpreters. With appropriate experience and training, sufficient interpreter consistency can be achieved.

Hypothesis 2 (see Table 4)

There was less than 1 percent conflict in the presence/absence of isobath interpretations for the 1.6m isobath. This 1 percent is depicted in Table 4 for both paired interpretations by an individual and between multiple interpreters. Mean displacement for the 1.6m isobath was 53m with a standard deviation of 56m.

(*8) The presence/absence record for the first hypothesis indicates that interpreter number three was the most consistent (2 percent) within his own repetitive interpretation attempts, but he was the least consistent (11 percent) in comparison with the other four interpreters. He was the only interpreter to be inconsistent with the 1.6m isobath interpretation. Interpreter three was also the only one rejected by the Kolmogorov-Smirnov test. He is considered to be less accurate and reliable (consistent) than the other interpreters.

(*9) Isobath displacement measurements between successive interpretations are summarized as mean and one standard deviation. The unitless measure was taken off the quadrangle by 0.1mm grid (0.1mm is equivalent to 25 m on the ground). This was converted to meters and is written above the original grid measure (Table 4).

Table 4 Consistency of presence/absence record and displacement measurements made from repetitive laboratory interpretations

HYPOTHESES (Ho)	# of Interpreters	Data Sets	PRESENCE/ABSENCE: Percent of Isobath Interpretations in conflict — by a Single Interpreter (interp. pairs)	Between Multiple Interpreters	DISPLACEMENT DATA/CALCULATIONS: Mean	1 S.D.	D-max.	D-critical	Kolmogorov-Smirnov test used		DECISIONS
(1) Each interpreter is as accurate and reliable as (consistent with) other interpreters.	1 / 4	Interpreter #1 vs. #2, 3 and 4	8%	6%	62m .265	84m .334	.0238	.1474	Two-sided Accept Ho if Dmax ≤ Dcrit.	Dmax ≤ Dcrit.	Accept Ho
	1 / 4	Interpreter #2 vs. #1, 3 and 4	5%	8%	76m .306	122m .486	.1437	.1474	Two-sided Accept Ho if Dmax ≤ Dcrit.	Dmax ≤ Dcrit.	Accept Ho
	1 / 4	Interpreter #3 vs. #1, 2 and 4	2%	11%	38m .151	42m .169	.2104	.1572	Two-sided Accept Ho if Dmax ≤ Dcrit.	Dmax ≥ Dcrit.	Reject Ho
	1 / 4	Interpreter #4 vs. #1, 2 and 3	5%	5%	78m .310	165m .659	.0438	.1509	Two-sided Accept Ho if Dmax ≤ Dcrit.	Dmax ≤ Dcrit.	Accept Ho
(2) ~1.6m isobaths are interpreted more accurately and reliably (consistently) than ~4m isobaths	5	~1.6m Isobaths (shallow)	1%	1%	53m .213	56m .226	.2048	Chi Square calculated	df = 2 sigma = .05	One-sided Accept Ho if x^2 calc. > x^2 tab. (46.03) (5.99)	Accept Ho
	5	~4m Isobaths (deep)	9%	14%	148m .592	299m 1.195		46.03	Chi Square tabulated x = 5.99		

Conflicting 4m isobath interpretations for paired interpretations by an individual was nine percent and was 14 percent between interpreters. Mean displacement for the 4m isobath was 148m with a standard deviation of almost 300m. A one-sided Kolmogorov-Smirnov test provides an easy acceptance of the hypothesis that the 1.6m isobaths were interpreted more accurately and reliably than the 4m isobaths.

The 4m isobath is interpreted much less consistently, both for its presence and its placement, than is the 1.6m radar isobath.

A REGIONAL DATA SET

Figure 11 summarizes the regional data set of maximum lake depths as determined from radar interpreted isobaths across the National Petroleum Reserve-Alaska. Pinpoint dots represent the centroid location of approximately 12,000 lakes with depths less than 1.6m. Middle-sized dots show the 8,000 lakes that have been interpreted to have the 1.6m isobath but not the 4m isobath. The largest circles indicate 600 lakes believed to be correctly interpreted to have the 4m isobath.

The maximum winter ice thicknesses of approximately 2m is important in controlling the resource value and potential use of these shallow water bodies (Mellor 1982b and 1983). Those lakes with the 1.6m and certainly those with the 4m isobath have much greater potential to harbor an over-wintering fish population than do those without those depths. Results from these radar-image interpretations have been used for: environmental assessments; locating water sources with the least potential for environmental conflict; safe winter trail and ice landing strip location; and other resource management considerations. They will continue to be used for environmental analyses and lacustrine resource management until more finite and accurate lake depths are acquired. Although improvements can be made, these regional interpretations may be used as an indicator of potential lake use before launching into expensive field verification.

The area south and west of Teshekpuk Lake has the greatest density of deep lakes (greater than 4m) and is indicated by a heavy solid line (Figure 11). Large concentrations of lakes with the 1.6m isobath are confined to the Arctic Coastal Plain and along a few river corridors in the foothills (compare Figure 11 with provinces in Figure 7).. As explained previously, very few lakes within the 30km coastal zone near the Arctic Ocean were correctly interpreted as greater than 4m deep. Also there are fewer lakes with the 1.6m isobath within this zone. Lakes with only the 1.6m as well as those with the 4m isobath increase in number inland.

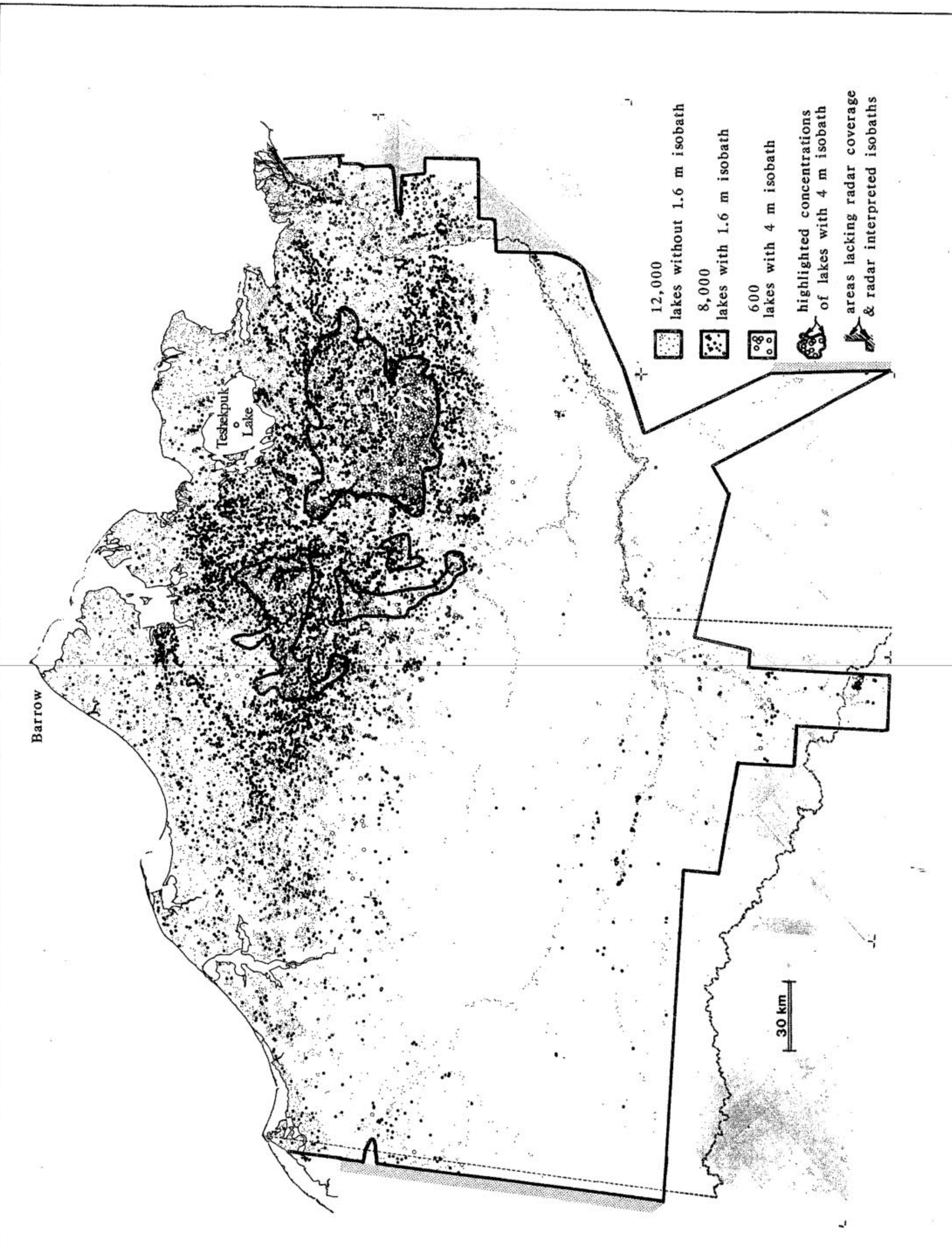


Fig. 11 Maximum radar-interpreted lake depths in NPR-A

SUMMARY

Many lacustrine basins on the Arctic Coastal Plain are too small (less than 10 hectares) to interpret the 4m or even the 1.6m radar image isobaths. However, the great majority of these small basins are less than 1.6m deep. These regional data segregate lakes into three depth classes (i.e. 0 to 1.6m; 1.6 to 4m; and greater than 4m). These data can be used to estimate water volumes for regions or individual lakes. Large summer water volumes can be contrasted with the dirth of winter water available under the thick April ice cover (approximately 1.6m).

Radar image coverage was not complete for all 12 quadrangles. For example, depth interpretations do not exist for some lakes within the Harrison Bay, Umiat, Misheguk Mountain, Howard Pass and Killik River quadrangles. See Figure 1 for the areas lacking radar-interpreted isobaths. The minimum size of the interpreted lakes was estimated to be 10 hectares but approximately 20,000 lakes seemed large enough to interpret one or more depth class(es) (i.e. less than 1.6m, 1.6m to 4m, or greater than 4m). The 1:250,000 scale radar images used were of fair-to-poor quality which limited resolution and interpretation accuracy for isobath presence and placement. The 1.6m isobath could be interpreted for lakes less than 10ha, but the 4m isobath could easily have been missed on a lake considerably larger than 10ha.

Field verification of radar isobaths was limited by: accuracy of lake fathometer measurements; geographic (areal) location of fathometer transects; and the small number of lakes sampled (157), particularly with respect to the number sampled with 4m isobaths (27). Some non-random selection and fathometer sounding of lakes with 4m isobaths helped resolve the problem of erroneous 4m isobaths interpreted in brackish lakes near the coast.

Statistical data describe the limitations of radar-interpreted isobaths and are summarized specific to each quadrangle at the bottom of all 12 quadrangles. Generally lakes less than 4m deep are correctly interpreted better than 90 percent of the time. Location of the 1.6m isobaths was usually within about plus-or-minus 100m from the estimated placement for the 1.6m fathometer transect depth.

Lakes greater than 4m deep were correctly interpreted less frequently. The 4m isobath was interpreted correctly in only 28 percent of the Northern Coastal Plain lakes sampled, but this error has been noted (X's through incorrect greater than 4m depths) on quadrangles with coastal lakes believed to be shallow and brackish. No statistical analysis has been attempted on the Northern Coastal Plain lakes after these corrections were made.

Four-meter isobaths were correctly interpreted 74 percent of the time in 19 mid-coastal plain test lakes and 100 percent on the single foothill lake. The placement of the 4m isobath was within approximately 150m of the 4m fathometer transect depth locations.

Radar images with better resolution and sequential coverage over a single winter season may become available in the future (e.g. synthetic aperture radar on the European Space Agency's ERS-1 satellite in 1990). This may provide more refined (half-meter isobath intervals to a maximum ice thickness of 2m) and more consistent lake depth interpetations regionally. Some comparisons with other Arctic lake regions such as Siberia and the Canadian Northwest Territories would assess the usefulness of radar for interpreting isobaths for the Arctic as a whole.

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